GLAST Science I

GLAST Mission Concept Review

28 September 1998

S. Ritz, code 661-GSFC

I) Overview of GLAST science -S. Ritz

II) GLAST science requirements document -N. Gehrels

The BIG Picture

GLAST will do fundamental science, with a very broad menu that includes:

- Systems with supermassive black holes
- Gamma-ray bursts (GRBs)
- Dark Matter
- Solar physics
- Probing the era of galaxy formation

GLAST draws the interest of both the the High Energy Particle Physics and High Energy Astrophysics communities.

Why γ's?

Gamma rays carry a wealth of information:

– γ rays do not interact much at their source: they offer a direct view into Nature's largest accelerators.

– similarly, the Universe is mainly transparent to γ rays: can probe cosmological volumes. Any opacity is energy-dependent (light interacts with light!).

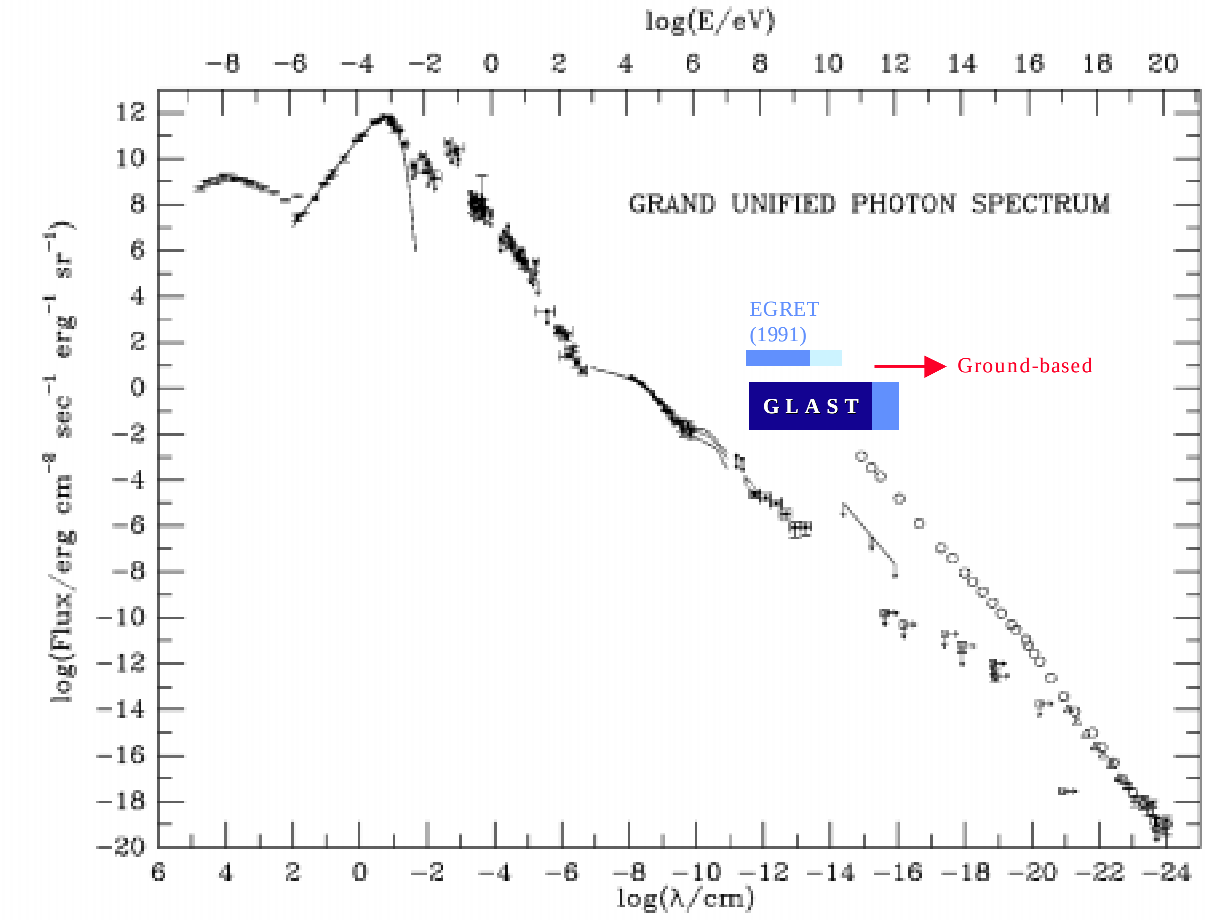
– conversely, γ rays readily interact in detectors, with a clear signature.

– γ rays are neutral: no complications due to magnetic fields. Point directly back to sources, etc.

Why this energy range? (20 MeV - > 300 GeV)

The Flux of Diffuse Extra-Galactic Photons

The Grand Unified Photon Spectrum (GUPS) c.a. 1990, Ressell and Turner



Note:

1 MeV=10^6 eV

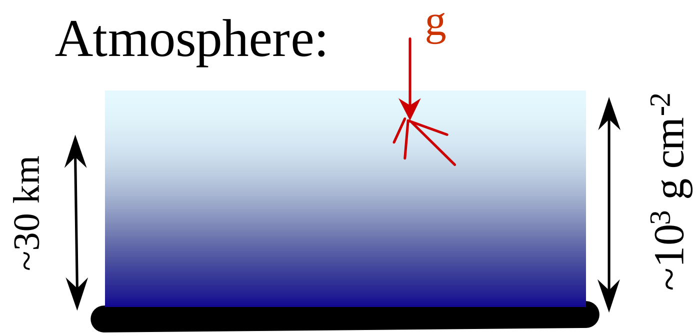
1 GeV=10^9 eV

1 TeV=10^{12} eV

1eV=1.6×10^{-19}J

Measurement techniques

Atmosphere:



For E_γ < ~ O(100) GeV, must detect above atmosphere (balloons, satellites, rockets)

For E_γ > ~ O(100) GeV, information from showers penetrates to the ground (Cerenkov)

Energy loss mechanisms:

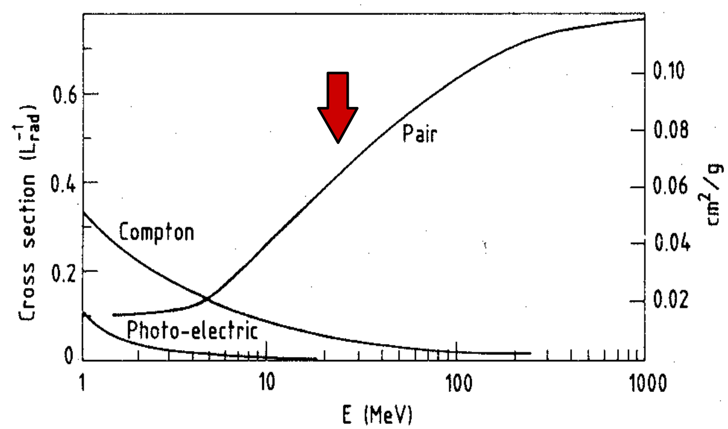
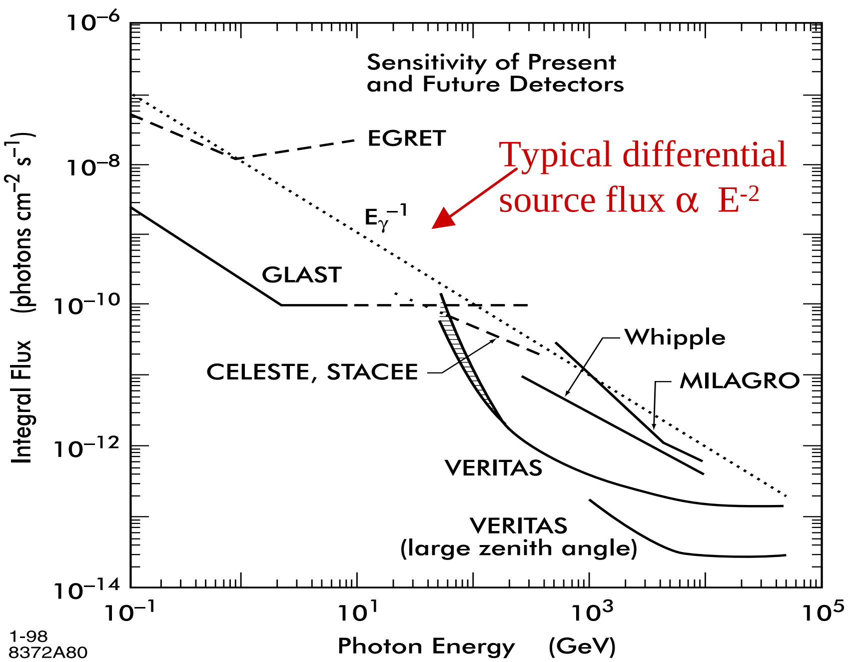


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

Unified gamma-ray experiment spectrum



Complementary capabilities

	ground-based	space-based
angular resolution	good	good
duty cycle	low	excellent
area	**H U G E !**	small
field of view	small	excellent (~20% of sky)
energy resolution	moderate	good, w/ small systematic uncertainties

GLAST is a key element in the program

The success of EGRET: probing new territory

History:

SAS-2, COSB (1970's-1980's) <u>exploration phase</u>: established galactic diffuse flux

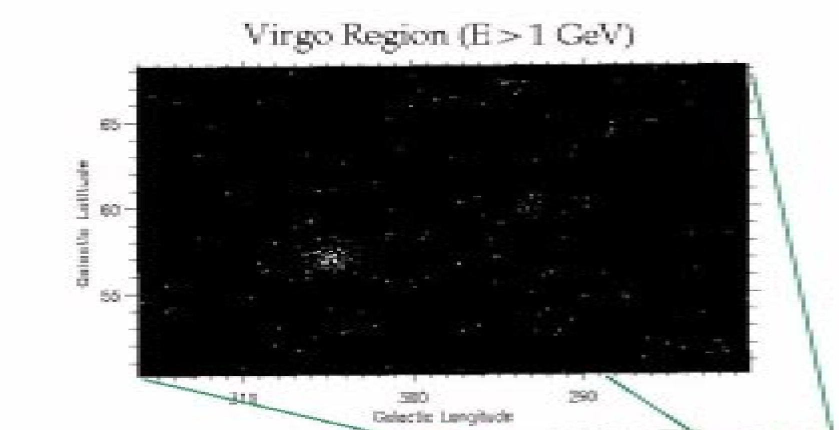
EGRET (1990's) <u>established field</u>:

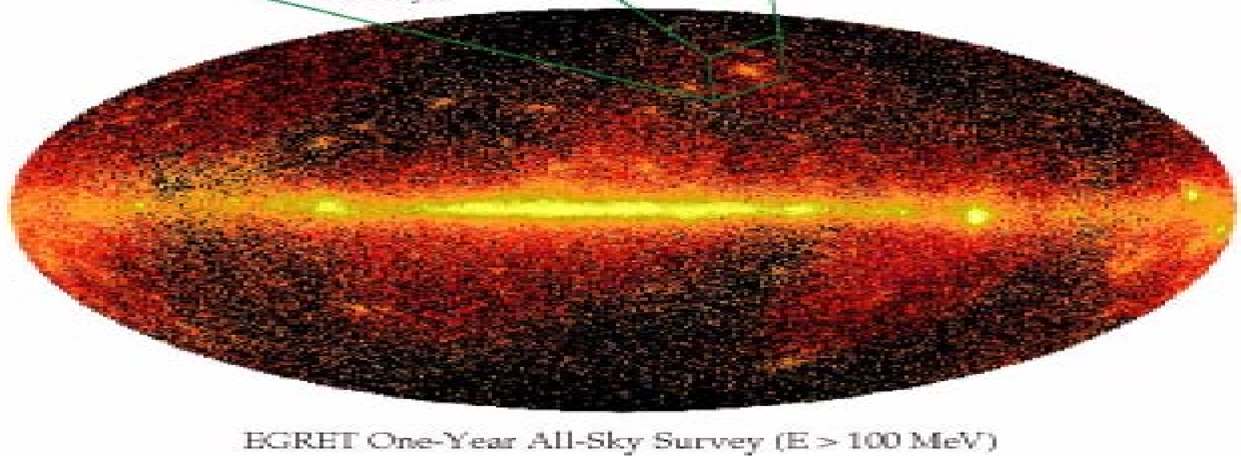
- increased number of ID'd sources by large factor;
- broadband measurements covering energy range ~20 MeV - ~20 GeV;
- discovered many yet-unidentified sources;
- discovered surprisingly large number of Active Galactic Nuclei (AGN);
- discovered multi-GeV emissions from gamma-ray bursts (GRBs);
- discovered GeV emissions from the sun

GLAST will explore the unexplored energy range above EGRET's reach, filling in the present gap in the photon spectrum, and will cover the very broad energy range ~ 20 MeV - 300 GeV (® 1 TeV) with superior acceptance and resolution. Historically, opening new energy regimes has led to the <u>discovery of totally unexpected new phenomena</u>.

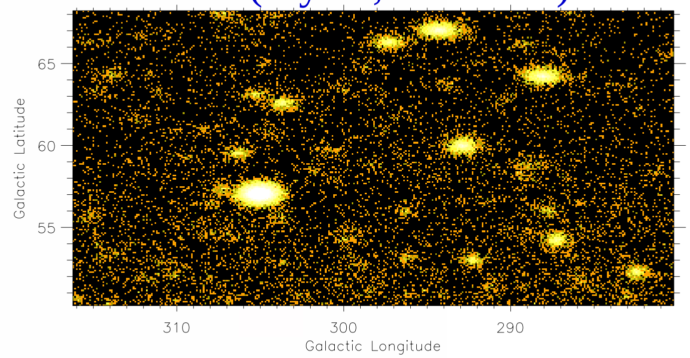
Diffuse Extra-galactic Background Radiation

Is it really isotropic (e.g., produced at an early epoch in intergalactic space) or an integrated flux from a large number of yet unresolved sources? GLAST has higher sensitivity to weak sources, with better angular resolution.





GLAST (1-year, E>1 GeV)

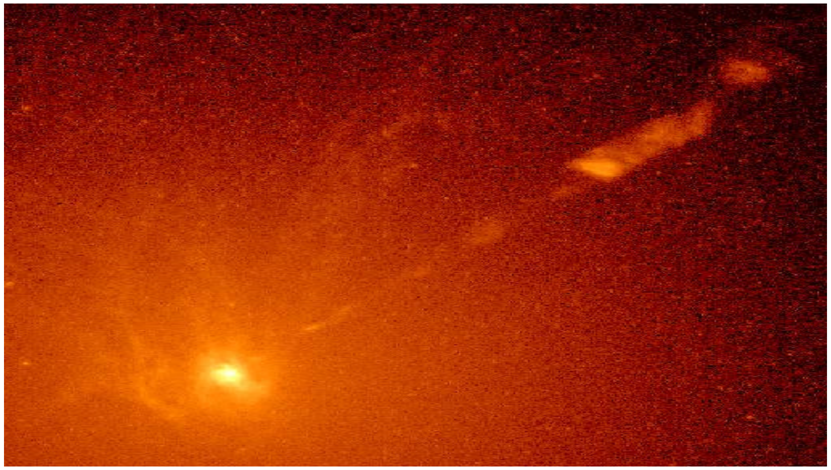


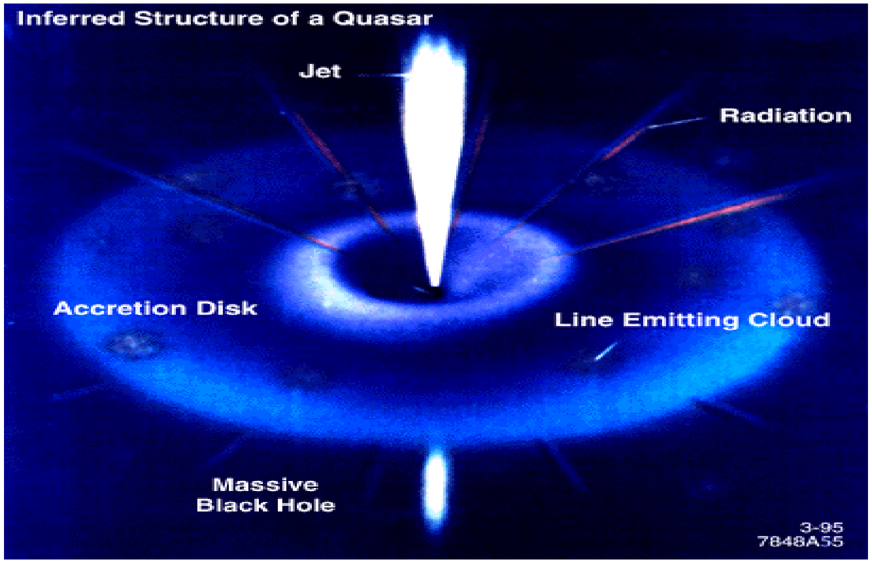
Active Galactic Nuclei (AGN)

Active galaxies produce vast amounts of energy from a very compact central volume.

Prevailing idea: powered by accretion onto super-massive black holes (10^6 - 10^{10} solar masses). Different phenomenology primarily due to the orientation with respect to us.

HST Image of M87 (1994)



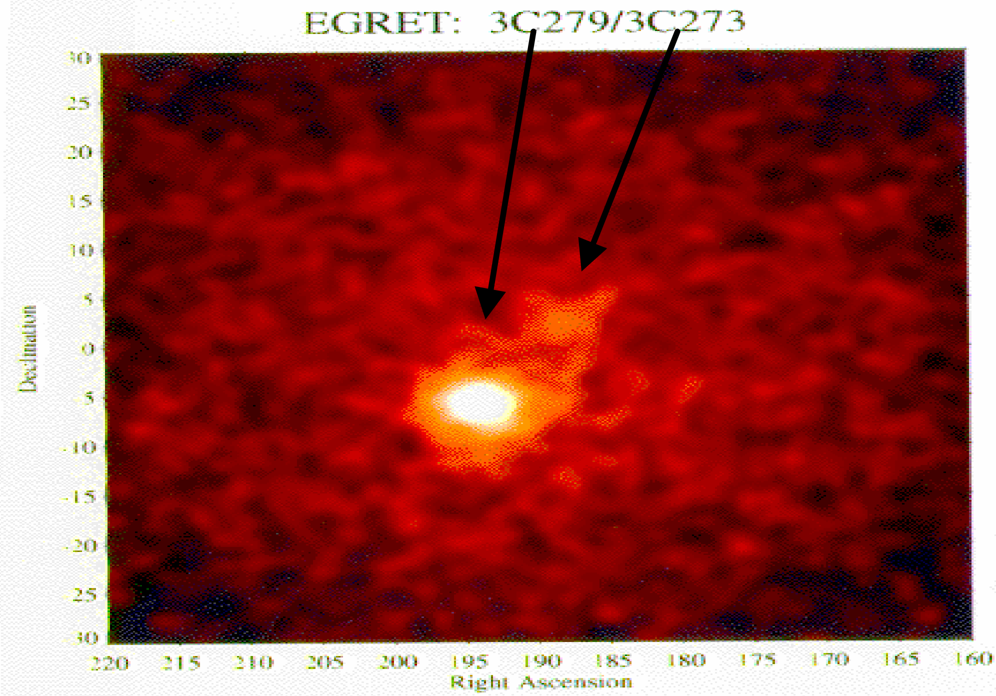


Models include energetic (multi-TeV), highly-collimated, relativistic particle jets. High energy γ-rays emitted within a few degrees of jet axis. Mechanisms are speculative; γ-rays offer a direct probe.

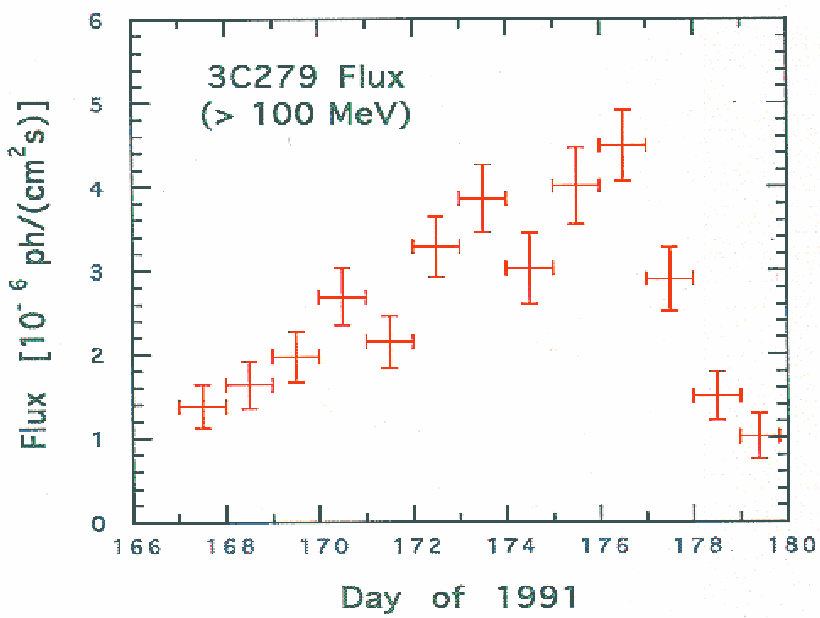
EGRET and 3C279

Prior to EGRET, the only known extra-galactic point source was 3C273; however, when EGRET launched, 3C279 was flaring and was the brightest object in the gamma-ray sky!

EGRET discovery image of gamma-ray blazar 3C279 (z=0.54)
E>100 MeV (June 1991)



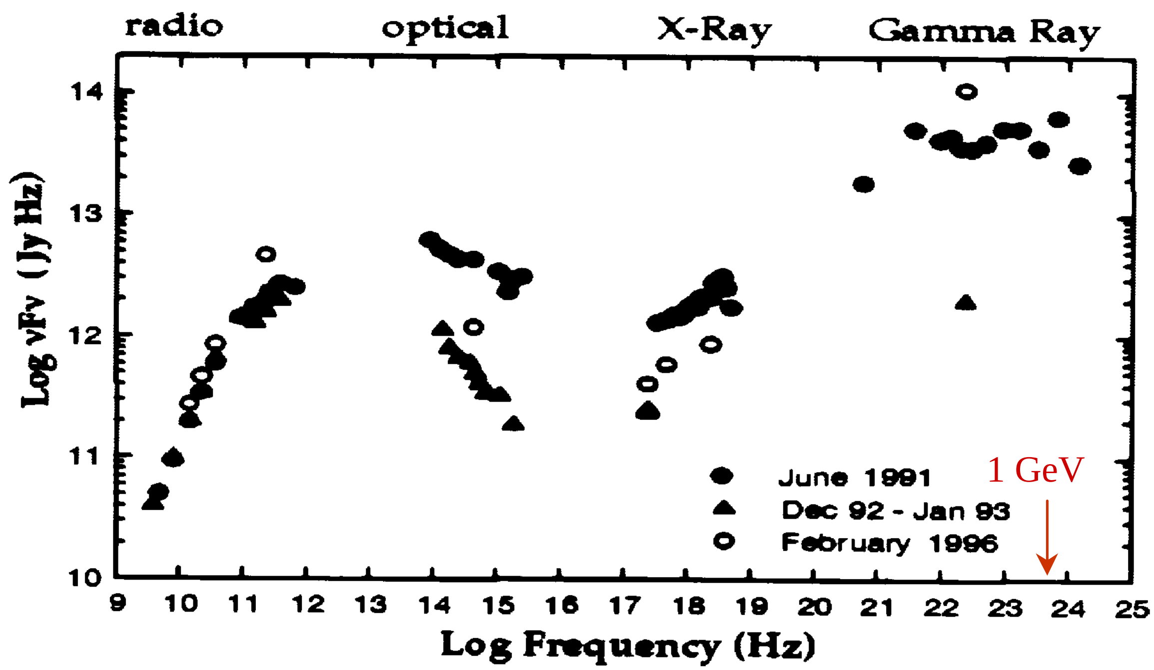
VARIABILITY: EGRET has seen only the tip of the iceberg.



AGN shine brightly in GLAST energy range

<u>Power output of AGN is remarkable. Multi-GeV component can be dominant!</u>

Estimated luminosity of 3C 279:
 ~ 10^{45} erg/s
corresponds to 10^{11} times total solar luminosity
just in γ-rays!! Large variability within days.



Multiwavelength Spectrum of 3C 279

Sum all the power over the whole electromagnetic spectrum from all the stars of a typical galaxy: an AGN emits this amount of power in JUST γ rays from a very small volume!

AGN: what GLAST will do

EGRET has detected ~ 60 AGNs. Extrapolating, GLAST should expect to see dramatically more -- at least several thousand:

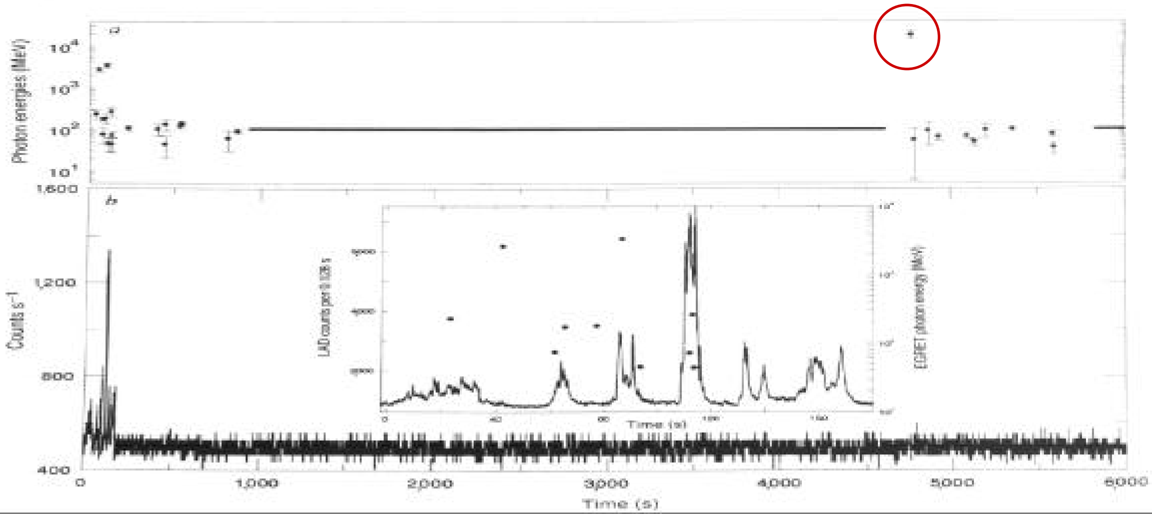
- Allows a statistically accurate calculation of AGN contribution to the high energy diffuse extra-galactic background.
- Constrain acceleration and emission models. How do AGN work?
- Large acceptance and field of view allow relatively fast monitoring for variability over time -- correlate with other detectors at other wavelengths.
- Probe energy roll-offs with distance (light-light attenuation): info on era of galaxy formation.
- Long mission life to see weak sources and transients.

Joining the unique capabilities of GLAST with other detectors will provide a powerful tool.

Gamma Ray Bursts (GRB)

GRBs discovered in 1960’s accidentally by the Vela military satellites, searching for gamma-ray transients (guess why!) The question persists : What are they??

EGRET has detected very high energy emission associated with bursts, including an 18 GeV photon ~75 minutes after the start of a burst:

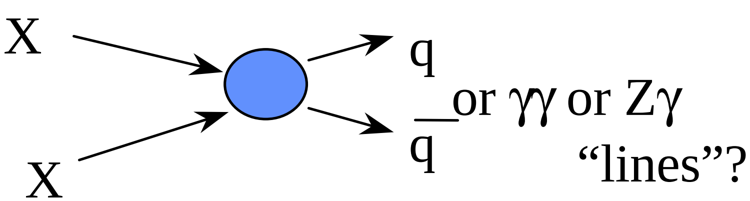


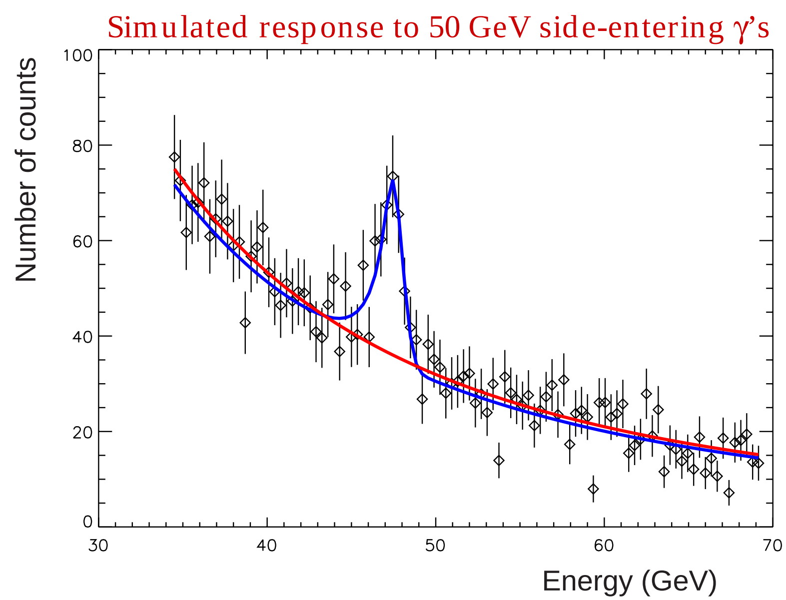
GLAST will provide definitive and unique information about the high energy behavior of bursts. How many have delayed, high energy activity??

WIMP Dark Matter Annihilations?

Extensions to the Standard Model of Particle Physics also provide good candidates for galactic halo dark matter. This would be a totally new form of matter.

If true, there may well be observable halo annihilations into mono-energetic gamma rays.





<u>Just an example of what might be waiting for us to find!</u>

PHYSICS

STRING INSTRUMENTS

String theory may soon be testable

The theory of strings, which attributes the infinite variety of the cosmos to the harmonies of subatomic membranes, has emerged over the past two decades as the leading contender for the "theory of everything." It would explain the four forces of nature—gravity, electromagnetism, and the weak and strong nuclear forces—as a single force with different manifestations. But how could such a theory ever be proved? The last time the four forces acted as one was at the big bang; to re-create those conditions, physicists would need a particle accelerator larger than the solar system, which Congress might be reluctant to fund. Despairing of the task, some scientists call theories of everything an exercise in theology. "For the first time since the Dark Ages," physicists Paul Ginsparg and Sheldon L. Glashow wrote 12 years ago, "we can see how our noble search may end, with faith replacing science once again."

That proclamation now seems premature. Researchers have devised the first astronomical probe of theories of everything and have also discovered that the four forces may unite under conditions short of the big bang. "Unification, the theory of everything, might actually be accessible experimentally," says Nima Arkani-Hamed of the Stanford Linear Accelerator Center.

The probe was conceived by Giovanni Amelino-Camelia of the University of Oxford and the Institute of Physics in Neuchâtel, Switzerland, and his colleagues. They propose using gamma-ray bursts to check whether the speed of light in a vacuum depends on its wavelength. According to special relativity, light has the same speed in a vacuum regardless of wavelength. Therefore, the detection of a wavelength-dependent speed would unearth a level of physical law more fundamental than relativity.

Variations in the speed of light are familiar to anyone who has looked at a prism. Because glass, water and other substances allow red light to go faster than blue, the prism splays white light into a rainbow.

Empty space, too, is a substance of sorts. By the laws of quantum mechanics, particles burble in and out of existence as the void fluctuates around complete emptiness. Present quantum theory, which incorporates special relativity but not gravity, says that these fluctuations affect all wavelengths of light equally. But theories of everything also allow for fluctuations in gravity, which might act as subatomic lenses that bend light. The shorter the wavelength of light, the more it might induce such lensing and the slower it would travel.

Although the retardation is predicted to be small, it might show up in gamma-ray bursts. Whatever their mysterious origins, these intense flashes travel billions of light-years and flicker frenetically. The blinking gives astronomers a handle on any dispersion: at shorter wavelengths, a flicker would register a moment after it appeared at longer wavelengths. Across a typical range of gamma rays, the time difference would be around 10 microseconds—not much, considering that the radiation has traveled for 10 billion years. But it may be just enough for current instruments to detect. And the Gamma-ray Large Area Space Telescope, scheduled to begin operation in 2004, will certainly have the requisite resolution.

Meanwhile there is another way that predictions of string theory could be detectable sooner: namely, if the forces of nature unite under unexpectedly mild conditions. Two years ago Edward Witten of the Institute for Advanced Study in Princeton, N.J., and Joseph D. Lykken of Fermi National Accelerator Laboratory in Batavia, Ill., realized that strings could come into play at lesser energies than previously assumed. In other words, maybe strings aren't so tiny.

The standard argument that strings should appear at high energies is based on theoretical extrapolations from the measured strength of the four forces. Electromagnetism and the two nuclear forces should become equally strong at the so-called Grand Unification scale. At a slightly higher energy, the Planck scale, gravity is supposed to join in. Both scales are trillions or quadrillions of times beyond the reach of today's accelerators.

But these extrapolations don't take into account a key prediction of string theory: the presence of extra dimensions, on top of the four familiar ones—three for space, one for time. New dimensions could lower both the Grand Unification scale (as shown recently by Keith R. Dienes, Emilian Dudas and Tony Gherghetta of CERN near Geneva) and the Planck scale (according to Arkani-Hamed, Savas Dimopoulos of Stanford University and Gia Dvali of the Abdus Salam International Center for Theoretical Physics in Trieste).

Specifically, string theory adds six minuscule dimensions, which Dienes compares to hairline cracks in the pavement. Each crack adds an extra (third) dimension to the two-dimensional road, but if it is small, your car rolls right over it.

If the crack is large enough and if your tire is small enough, however, your car rattles. Similarly, if the extra dimensions of space are large enough and a particle is small enough, the particle could begin to vibrate in those dimensions. New harmonics would develop, generating new particles—and altering the way the electromagnetic and the two nuclear forces are transmitted. Gravity might shift in a telltale way, too: for simple geometric reasons, extra dimensions would cause gravity to weaken more rapidly with distance. Experimenters are starting to look for such an effect.

Lower unification scales would allow the Large Hadron Collider, now being built at CERN, to make strings. To be sure, that prospect is still speculative. "All these proposals are in the spirit of 'unlikely to be right, but so extremely interesting if they are that they are well worth thinking about,'" says Sean M. Carroll of the University of California at Santa Barbara. But along with other hints of new physics—the neutrino mass, the cosmological constant, the odd behavior of meson particles [see "The Asymmetry between Matter and Antimatter," on page 76]—they suggest that we won't need to take a theory of everything on faith after all. —*George Musser*

News and Analysis

24 SCIENTIFIC AMERICAN October 1998

Although the retardation is predicted to be small, it might show up in gamma-ray bursts. Whatever their mysterious origins, these intense flashes travel billions of light-years and flicker frenetically. The blinking gives astronomers a handle on any dispersion: at shorter wavelengths, a flicker would register a moment after it appeared at longer wavelengths. Across a typical range of gamma rays, the time difference would be around 10 microseconds—not much, considering that the radiation has traveled for 10 billion years. But it may be just enough for current instruments to detect. And the Gamma-ray Large Area Space Telescope, scheduled to begin operation in 2004, will certainly have the requisite resolution.

Other topics include….

- Supernova remnants and the origins of cosmic rays
- Pulsars
- Unidentified gamma-ray sources
- Primordial black holes and other exotic relics from the Big Bang
- Solar physics
- …..

Most important: ***What is there to discover?***

Summary

- GLAST will address many important questions:
  - What is going on around black holes? How do Nature's most powerful accelerators work? (are these engines really black holes?)
  - What are the unidentified sources found by EGRET?
  - What is the origin of the diffuse background?
  - What is the high energy behavior of gamma ray bursts?
  - What else out there is shining gamma rays? Are there further surprises in the poorly measured energy region?
  - When did galaxies form?
- Large menu of "bread and butter" science
- Large discovery potential

Next: how science goals translate into mission science requirements → N. Gehrels (FST co-chair)